Study of solar-thermal collector assisted hybrid split air conditioner

Chetan Brahmankar[1], Hrishikesh Bhushan[2], Akshay Ghule[3], Himanshu Ranjan[4]

[1,2,3,4] *Dept. of mechanical engineering, Dr. D.Y Patil Institute of Technology, Maharashtra, India*

Abstract - *In this paper we used the solar thermal collector to reduce the electricity consumption of compressor. Compressor which is the most electricity-consuming unit of air conditioner essentially, compresses low-pressure fluid which in turn gets heated. A solar collector panel can assist in heating the fluid and thus can reduce the load on the compressor, which in turn will reduce the electricity consumption. In a typical house using air conditioners, the electricity required for cooling can be as high as 30% of the total electricity used in commercial complexes, this percentage is even higher.*

The study analyzed the performance of solar-thermal collector assisted hybrid split air conditioner and conventional electricity powered air conditioner, compare energy performance and evaluate energy saving due to solar-thermal collector assisted hybrid split air conditioner. Solar collector absorbs sunlight and converts to usable heat. The evacuated tube prevents the loss of heat from plate to surrounding when there is temperature difference between inside of the tube and the outside ambient air.

We are able to reduce the electricity consumption of air conditioner close to 30% which in turn reduces CO_2 emission of thermal power plant.

***Key Words*: Hybrid Air Conditioner, Evacuated tube, solar collector, Energy Saving, R410a**

1. INTRODUCTION

Solar energy is one of the most available forms of energy on the Earth's surface, besides; it is very promising and generous. The earth's surface receives a daily solar dose of 10E+8 KW-hr, which is equivalent to 500 000 billion oil barrels that is one thousand times any oil reserve known to man.

The demand of air conditioning has greatly increased since the last decade due to the effect of climate change and global warming. High fuel price and electric tariff makes conventional air conditioner not economical in the long run. Furthermore, generating electricity from fossil fuel emits greenhouse gases and worsen the global warming. This paper presents the investigation into the feasibility of solar assisted vapour compression air conditioning system in providing thermal comfort in India. Solar energy is harvested through solar collector which provides part of compression pressure by heating the refrigerant under constant volume, thus reducing energy consumption by lowering the load on the electric compressor.

The objectives of this study are to design and integrate solar hybrid system into conventional air conditioning system, to reduce air conditioning electricity consumption by up to 45%, and to reduce electricity peak load during the day.

2. EVACUATED TUBE

A variety of technologies exist to capture solar radiation, but of particular interest of authors is evacuated tube technology. Numerous authors have noted that ETSCs have much greater efficiencies than the common FPC, especially at low temperature and isolation. For instance, Ayompe et al. Conducted a field study to compare the performance of an FPC and a heat pipe ETSC for domestic water heating system. With similar environmental conditions, the collector efficiencies were found to be 46.1% and 60.7% and the system efficiencies were found to be 37.9% and 50.3% for FPC and heat pipe ETSC, respectively. An ETC is made of parallel evacuated glass pipes. Each evacuated pipe consists of two tubes, one is inner and the other is outer tube. The inner tube is coated with selective coating while the outer tube is transparent. Light rays pass through the transparent outer tube and are absorbed by the inner tube. Both the inner and outer tubes have minimal reflection properties. The inner tube gets heated while the sunlight passes through the outer tube and to keep the heat inside the inner tube, a vacuum is created which allows the solar radiation to go through but does not allow the heat to transfer. In order to create the vacuum, the two tubes are fused together on top and the existing air is pumped out. Thus the heat stays inside the inner pipe sand collects solar radiation efficiently. Therefore, an ETSC is the most efficient solar thermal collector. An ETSC, unlike an FPC, can work under any weather conditions while it provides acceptable heat efficiency.

2.1 Why an evacuated tube solar collector (ETSC) is preferable?

The single-walled glass evacuated tube is popular in Europe. Badar et al studied the thermal performance of an individual single walled evacuated tube with direct flow type coaxial piping based on analytical steady state model. Kim et al investigated the thermal performance of an ETSC with four different shaped absorbers both experimentally and numerically. Four different shapes are: finned tube (Model I), tube welded inside a circular fin (Model II), U tube welded on a copper plate (Model III) and U tube welded inside a rectangular duct .Firstly, by considering only the beam radiation, the performance of a single collector tube was observed and it was found that the incidence angle has great influence on the collector efficiency. Model III had the highest efficiency with small incidence angle but the efficiency of model II became higher than model III with the increment of incidence angle. The incidence angle has negligible impacts on collector performance while considering the diffuse radiation and the shadow effects and model III is found to have the best performance for all ranges of the incidence angle.

3. Solar Hybrid Air Conditioning System

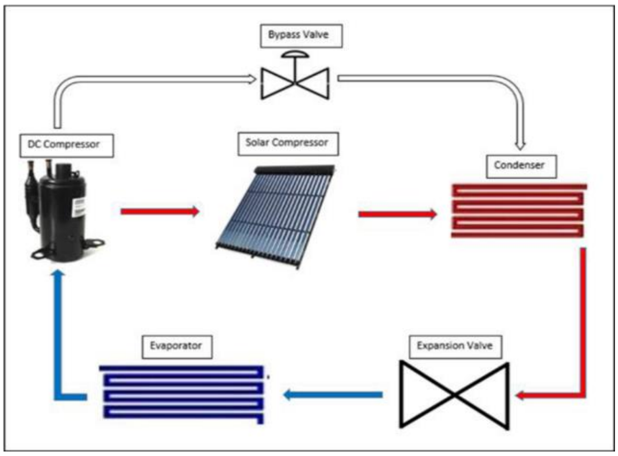


Figure 1. Solar Hybrid Air Conditioning System

Figure 1 shows the evacuated tube solar collector is installed between the compressor and condenser. The solar collector consists of high efficient vacuum tube which provides part of compression pressure and heating by further superheating the refrigerant. The higher pressure and larger temperature difference enhance the condensation process in the condenser, resulting in high pressure liquid refrigerant. This configuration greatly reduces energy consumption by reducing the load on electric compressor.

3.1 Refrigerant Cycle

During refrigeration process, the refrigerant experiences huge change in thermodynamic properties and involves heat energy transfer to the surroundings through the heat exchangers [5]. During the operation of a vapour compression refrigeration system, the following processes occurs as shown in Figure 2

Process 1-2s: Compression

A reversible, adiabatic (isentropic) compression of the refrigerant. The saturated vapour at state 1 is superheated to state 2.

$$w_c = h_{2s} - h_1 \text{------(1)}$$

Process 2s-3: Condensation

An internally, reversible, constant pressure heat rejection in which the refrigerant is de-superheated and then condensed to a saturated liquid at state point 3.

$$q_h = h_{2s} - h_3 \text{------(2)}$$

Process 3-4: Throttling and expansion

An irreversible throttling process in which the temperature and pressure decrease at constant enthalpy.

$$h_3 = h_4 \quad \text{-----(3)}$$

Process 4-1: Evaporation

An internally, reversible, constant pressure heat interaction in which the refrigerant is evaporated to a saturated vapour at state point 1

$$q_L = h_1 - h_4 \text{--------(4)}$$

The thermal efficiency of the cycle can be calculated as:

$$\eta = \frac{q_{evap}}{w_{comp}} = \frac{h_1 - h_4}{h_{2s} - h_1} \text{------(5)}$$

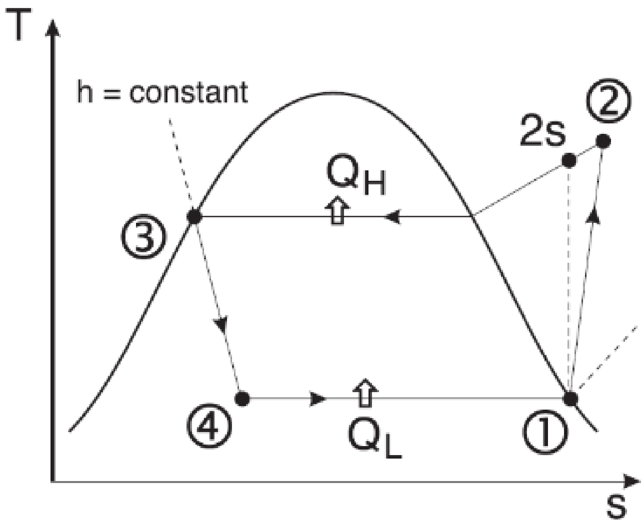


Figure 2. T-s diagram of vapour compression refrigeration cycle

3.2 Solar Hybrid Vapour Compression Refrigeration Cycle.

The evacuated tube solar collector is installed between the compressor and condenser, providing part of compression pressure and heating by further superheating the refrigerant. Figure 5 shows the parameters of solar hybrid

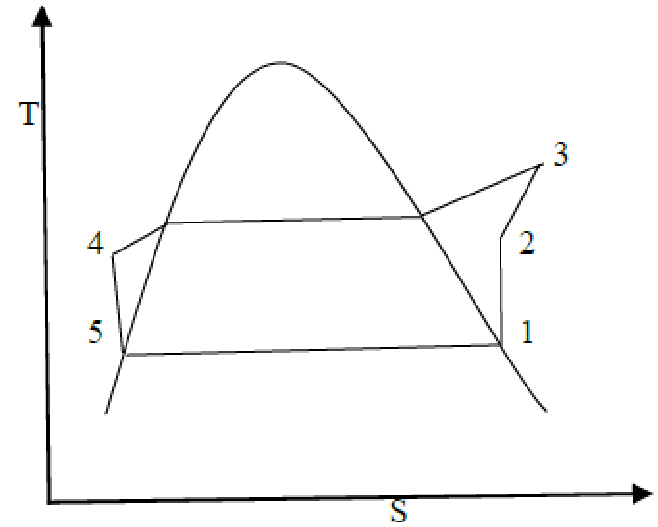


Figure 5: Diagram of solar hybrid vapour compression refrigeration cycle

Where T and S are Temperature and entropy respectively

Point 1: P_1, T_1 :Evapotator Outlet

Point 2: P_2,T_2 :Compressor Outlet

Point 3: P_3,T_3 :Solar Plate outlet

Point 4: P_4,T_4 :Condenser Inlet

Point 5: P_5,T_5 : Evaporator Inlet

Where, P and T are Pressure and temperature.

Process 1-2: Electric AC compressor

Process 2-3: Solar Collector

Process 3-4: Condenser

Process 4-5: Expansion valve Process

Process 5-1: Evaporator

3.3 R410a Refrigerant

Because of environmental and energy efficiency concerns, the air-conditioning industry has been forced to look for alternatives to long-standing fluids such as CFC's and HCFC's and examine new technologies that will allow air conditioning systems, using the next generation of refrigerants, to be more efficient in their energy consumption than their predecessors [1]. R410A is one of the most attractive potential replacements for residential small air conditioning system. The small residential air conditioner is one of the simplest vapor compression refrigeration systems: composed only of a compressor, a condenser, an evaporator, a capillary tube and related attachments. The steady state characteristics of the R4 1 OA system as well as the R22 system are well established.

3.4 Single walled glass evacuated tube

The solar collector provides part of compression pressure by heating the refrigerant under constant volume. Ideal gas law states that *PV=nRT*, where *P* is absolute pressure of gas, *V* is volume of gas, *n* is number of moles of gas, *R* is ideal gas constant, and *T* is absolute temperature of gas. During the 2nd stage compression, *V*, *n*, and *R* are kept constant, deriving the ideal gas law into $\frac{P_1}{T_1} = \frac{P_2}{T_2}$, where $P_1$is the input pressure, is input temperature, is the output pressure, and is output temperature. Therefore, the higher the temperature of solar collector, the higher the pressure of refrigerant.

Figure 3. Evacuated Tube Solar Collector

Evacuated tube solar collectors consists of series of glass tubes which has the air evacuated out, creating a vacuum between the glass tube surface and absorber surface. The vacuum layer eliminates heat loss through conduction and convection, leaving radiation as the only heat loss mechanism. Figure 3. Tube evacuated solar collector consists of long copper tube which directs the refrigerant flow through the evacuated tube. This allows a greater heat exchanging area which is highly desirable due to the low thermal conductivity of refrigerant vapor.

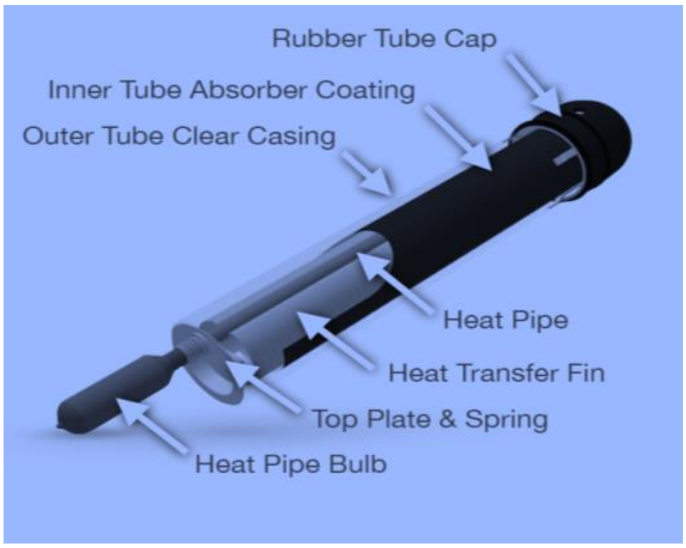


Figure: 4 Cross-sectional view of evacuated tube

It is made from two glass tubes that are fixed at both ends.The inner tube has high efficiency of selective coating which absorbs 95% sunlight.The space between the tubes is evacuated to form an insulating vacuum.The fins of aluminium which hold the heat pipe closer to glass wall which increases transfer.

The solar radiation heat flux is solved using fair weather condition radiation equations, and then solar radiation load is considered as a heat source term in the energy equation. For coated glazing, the spectral transmissivity and reflectivity at any incident angle are approximated from the normal angle of incidence.

Transmissivity, is given by [8].

$$T(\theta,\lambda) = T(0,\lambda)Tref(\theta) \quad (6)$$

$$Tref(\theta) = a^0 + a^1\cos(\theta) + a^2\cos(\theta^2) + a^3\cos(\theta^3) + a^4\cos(\theta^4) \quad (7)$$

Reflectivity is given by

$$R(\theta,\lambda) = R(0,\lambda)[1 - Rref(\theta)] + Rref(\theta) \quad (8)$$

$$Rref(\theta) = b^0 + b^1\cos(\theta) + b^2\cos(\theta^2) + b^3\cos(\theta^3) + b^4\cos(\theta^4) \quad (9)$$

Where:

(0,$(0,)) = normal transmissivity = normal reflectivity

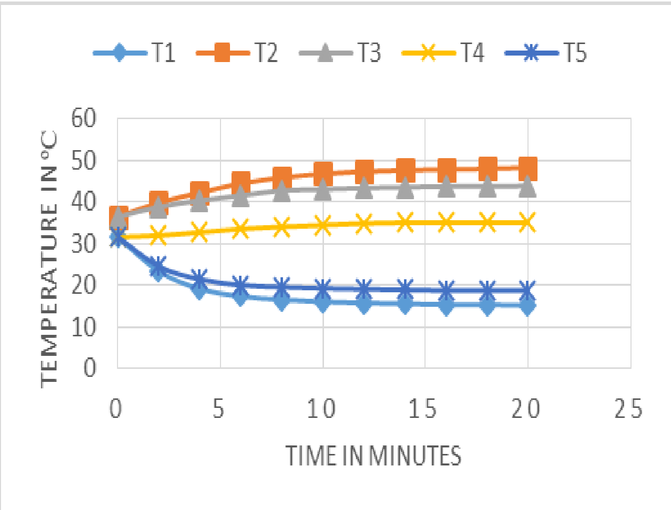
4. CALULATION AND RESULTS

4.1 Specification for Experimental procedure:

Colling capacity 0.75ton

Room specification 5.7*3.3*2.8 m^3

Reading taken at set temperature at 22°C



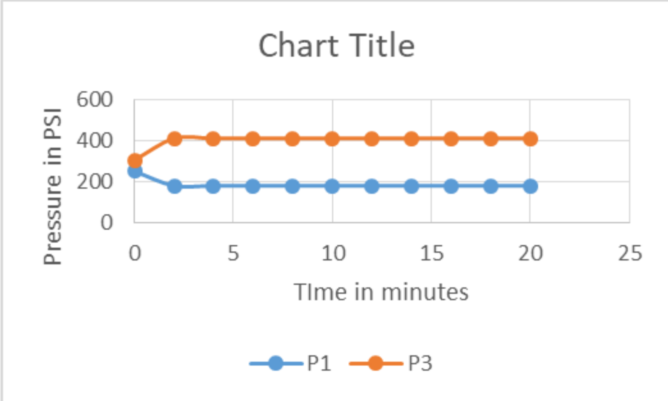


Chart 2: pressure vs time

Where P1: suction Pressure (gauge)
P3: Discharge Pressure (gauge)

4.2 Theoretical Calculations

Compressor work =h_2-h_1

=460-422

=38 kj/kg

Cooling effect = h_1-h_4

=422-275

=147 kj/kg

Theoretical COP = 3.86

4.3 Actual calculation

Actual COP = (Cooling Capacity in BThU/Hr)/ (Energy consumed in Kj/Hr)

= 9000/2556= 3.714

Energy meter reading for one hour(hybrid solar AC)

=2556 KJ

Energy consumed by conventional 2 star AC for 1 hr

= 3600 Kj

Energy saving achieved = 29%

5. Energy Saving:

The higher the refrigerant temperature, the higher the system energy saving, thus contributing to lower power consumption. However, the maximum energy saving is limited at 160°C of refrigerant temperature at condenser inlet. The designated condenser is unable to remove any excess heat energy from the refrigerant at temperature higher than 160°C. In short, the solar compressor provide energy saving when refrigerant temperature at condenser inlet is in the range of 69.2°C up to 160°C. At refrigerant temperature lower than 69.2°C, the energy saving is solely supported by the highly efficient DC compressor.

Energy savings are calculated by comparing the change in enthalpy of refrigerant through the electric compressor of both conventional and solar hybrid system. Compressor energy saving, S is given by

$$S = 1 - \frac{h_{xa} - h_1}{h_{2a} - h_1} \, x \, 100\% \qquad (10)$$

Where h_{2a} and h_{xa} is refrigerant enthalpy at electric compressor outlet foe conventional system and solar hybrid system.

6. CONCLUSION:

Solar air conditioning system is a great innovation which pushes solar energy leaps ahead while promoting positive impact on the environment. The system is able to achieve up to 29% energy saving during daytime, thus significantly reduces the electricity peak load during the day. The main modifications needed are AC compressor, higher capacity condenser and evacuated tube solar collector.

7. ACKNOWLEDGMENT:

I take this opportunity to express my gratitude and indebtedness to my guide Prof. Arun D Sonar, Prof. Aniket Phatangare, who has been constant source of guide and inspiration in preparing his paper. I also thankful to Everyone who helped me to completing the paper work and those who have directly or indirectly helped for completion of this Report I completing this Paper work successfully.

8. REFERENCES:

[1] M. Khalaji Assadi, S. I. Gilani and T. C. Jun Yen ,"DESIGN a solar hybrid air conditioning compressor system",EDP Sciences, 2016

[2] V Mittal ,KS Kasana ,NS Thakur, "The study of solar absorption air-conditioning systems", November 2005 2925.

[3] Masaya Okumiya, Takuya Shinoda, Makiko Ukai, Hideki Tanaka, Mika Yoshinaga, Kazuyuki Kato Toshiharu Shimizu, "Performance analysis of the solar- thermal assisted air-conditioning system installed in an office building", 2011.

[4] Etc Solar Collector Product o=Overview , © Apricus Inc - 2015.

[5] M.A.Sabiha a, R.Saidur b,n, SaadMekhilef c, OmidMahiand "Progress and latest developments of evacuated tube solar collectors",2014